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Soil Burial Tests:

Effect of Soil Burial Exposure on the Properties of Adhesives and Pressure-Sensitive Tapes

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The effects of long-term soil burial on some physical properties of adhesive bonded test specimens and pressure-sensitive adhesive tapes are presented. Changes in these measured properties are discussed and interpreted in terms of typical material characteristics. Additionally, the engineering implications of these changes are explored. Such implications include:

(i) Adhesive bonding appears to be a satisfactory means of fastening structures together for direct soil burial; however, care must be exercised to insure proper joint design and bonding procedures.

(ii) Both rubber and vinyl pressure-sensitive tapes provide sufficient retention of properties for prolonged underground service, but glass cloth and aluminum backed tape should be used only for temporary service.

I. INTRODUCTION

Included in the Bell System study of direct soil burial effects on the properties of material for telephone plant were a number of adhesives and pressure-sensitive adhesive tapes.

The 1950s and 1960s were a period of significant growth for adhesives technology, as witnessed by the number and diversity of products, applications, and publications related to the field. Few, if any, applications for buried adhesively bonded structures existed at the beginning of this program, but developments in that direction were easily predictable.

General usage of adhesives by the Bell System was initially cautious because of insufficient data and inadequate tests for evaluating

durability and reliability of bonded assemblies. However, with the development of better test methods and greater understanding of environmental deterioration, telephone applications of adhesives have increased manyfold.

Pressure-sensitive adhesive tapes have enjoyed a very rapid increase in usage within the Bell System. Many applications can be categorized as electrical insulations, such as splice protection, but more and more uses are being classed as mechanical holding, such as packaging, name-plate mounting, coil wrapping, duct sealing, leak stoppers, surface protectors, etc. All of the tapes selected for this program had been used for some form of cable splicing where outdoor exposure would be encountered. With the emphasis on buried plant, additional testing of tapes under direct soil burial was considered advisable.

Since the fields of structural adhesive bonding and tapes are quite diverse in chemistry as well as application and testing, they will be discussed separately.

II. ADHESIVES

2.1 *Description of Adhesives Tested*

2.1.1 *Types of Material*

The adhesives tested in this program were evaluated as prepared lap shear joints, with either glass fiber laminate or stainless steel substrates. A total of 25 different sample types were prepared and subjected to the two soil environments (topsoil and subsoil) at Roswell, New Mexico, and Bainbridge, Georgia.[1] The adhesives included epoxy (both simple formulation and proprietary), modified phenolics, and a polysulfide rubber.

2.1.2 *Expected Service Life*

Most adhesives are expected to have service lives greater than the structures that they bond, which is typically twenty to forty years in the Bell System. The determination of service life of an adhesive becomes a complex problem since, in addition to the bulk adhesive, there are the substrates and the very critical interfaces all of which are part of the adhesive joint and subject to environmental degradation. Attack at an interface may indicate that the substrate was not properly cleaned or prepared instead of that the adhesive was not resistant to the environment. This condition will be demonstrated in the discussion of test results. Other factors contributing to the service life

of an adhesive joint besides environment and surface preparation include the joint design, stress levels (both static and dynamic), stress mode, and the adhesive application and curing conditions.

2.2 *Test Methods*

2.2.1 *General*

The test method selected for the evaluation of the adhesives in this study was the lap shear test* detailed in ASTM D1002.[2] This method is reasonably simple, convenient, inexpensive, and adaptable to a large variety of data-generating modifications. Briefly, two substrates are bonded together as shown in Fig. 1, then the tensile force per unit

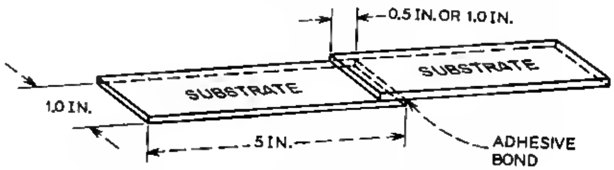

Fig. 1—Overlap shear test specimen.

area necessary to rupture that joint is measured with a suitable testing machine.

Test results can be influenced by a number of factors other than adhesive formulation. Some of these are listed in Table I. In this study, as many of the variables as possible relating to the specimen preparation and testing were held constant.

2.2.2 *Substrates*

Two substrates were selected for this program, a glass fiber laminate† and Type 302 stainless steel. The bases for selecting these two substrates were the attractive economics associated with glass fiber laminates for underground structures and the traditional corrosion resistance of the stainless steel.

2.2.3 *Sample Preparation*

Since the cleaning and preparation of the substrates is one of the most important steps in the adhesive bonding process, particular

* Also known as "overlap shear" and "tensile shear" test.
† Per ASTM D1532.

TABLE I—SOME VARIABLES AFFECTING LAP SHEAR TEST RESULTS

Length and width of overlap
Thickness of adhesive
Modulus of substrate
Modulus of adhesive
Surface preparation of substrate
Rate of testing
Curing conditions
Ambient conditions

care was taken to guarantee the uniformity of the samples. The glass fiber substrates were 1-inch × 5-inch specimens cut, using a diamond saw blade, from 1/8-inch-thick sheets. These substrates, prepared by process A in Table II, were then bonded with a 1-inch overlap. The stainless steel substrates were blanked 5 inches long from flat wire stock 1 inch wide × 0.062 inch thick. These substrates were prepared by procedure B, C, or D of Table II and bonded with a 1/2-inch overlap.

2.2.4 *Sample Testing*

After the desired burial duration and removal of the bonded samples from the two burial levels* at the two test plots, all of the samples were washed with tap water and visually inspected. The samples were then conditioned for 30 days at 95°F and 90 percent relative humidity prior to testing.

2.2.5 *Materials*

The adhesives used to bond the glass fiber laminate substrates are described in Table III. Reference numbers (171 to 181) were carried through the program and continued here for organizational purposes. Seven of these adhesives contain proprietary materials whose contents are not freely disclosed by the manufacturers and therefore they will be described in general terms. Table IV contains the information on adhesives used to bond the stainless steel substrates with #191 to 196 used in the initial phase and #197 to 204 in the second phase.

Most of the adhesives in this study were based on epoxy resins which were formulated with appropriate curing agents, modifiers, fillers, flexibilizers, etc. Several excellent texts[3–5] are available which offer comprehensive studies on the chemistry of epoxies and their curing mechanisms and should be referred to for additional information.

* Topsoil and subsoil, 6 inches and 18 inches below the surface respectively.

Cured epoxy resins, generally, because of their chemical structure, are quite resistant to chemical attack and, presumably, also biological attack. It would be expected that most of the conventional epoxy systems in the study would perform very well, unless a substrate problem occurred (as with both the glass fiber laminates and the initial group of stainless steel specimens).

The phenolic adhesives #179, 180, 194, and 195 are based on heat-curable phenolic resins compounded with either thermoplastic, such as poly (vinyl formal), or elastomeric polymers, such as nitrile rubber.

TABLE II—PREBOND TREATMENTS FOR LAP SHEAR SAMPLES

A
For Glass Fiber Laminate Only 1. Sandblast. 2. Trichlorethylene wipe prior to bonding.
B
For Stainless Steel 1. Vapor degrease. 2. Immerse in solution, 2.62% sodium metasilicate, 0.26% Triton X200 (Rohm & Haas) in deionized water. 3. Rinse in 150°F deionized water. 4. Rinse in cold deionized water. 5. Dry at 150°F.
C
For Stainless Steel 1. Vapor degrease. 2. Immerse in solution, 10% trisodium phosphate, 3.6% Triton X200, 86.4% water for 15 minutes at 150°F. 3. Rinse on hot water. 4. Rinse in distilled water. 5. Blow dry with oil-free air.
D
For Stainless Steel 1. Vapor degrease. 2. Immerse 15 minutes in 37% (by volume) concentrated hydrochloric acid in water at room temperature. 3. Rinse in cold water. 4. Rinse in distilled water. 5. Blow dry with oil-free air.

TABLE III—ADHESIVE SYSTEMS FOR GLASS FIBER SUBSTRATES

Reference Number	Adhesive Description	Surface* Preparation	Cure Cycle
171	Liquid DGEBA epoxy resin plus 8 phr† diethylaminopropylamine	A	2 hrs 165°F
172	Liquid DGEBA epoxy resin plus 20 phr liquid aromatic primary amine blend (m-Phenylenediamine/methylenedianiline)	A	1 hr 250°F
173	Liquid DGEBA epoxy resin plus 7 phr proprietary curing agent plus 50 phr high-viscosity polyamide resin	A	4 hrs 175°F
174	Proprietary, two-part, nominally room temperature curing, modified DGEBA epoxy-based adhesive. Mix ratio 100:13 pbw	A	2 hrs 165°F
175	Liquid DGEBA epoxy resin plus 54 phr polyamide resin	A	1 hr 250°F
176	Diluent modified liquid DGEBA epoxy blend plus 50 phr liquid polysulfide polymer plus 22.5 phr tris (dimethylaminomethyl) phenol	A	1 hr 250°F
177	Proprietary, two-part aluminum metal filled, nominally room temperature curing, epoxy repair kit	A	1-1/2 hrs 160°F
178	Proprietary, paste, modified DGEBA epoxy based formulation plus 6 phr diethylaminopropylamine	A	1 hr 165°F plus 1 hr 225°F
179	Proprietary poly (vinyl formal)-modified phenolic tape	A	30 min 325°F
180	Proprietary nitrile rubber-modified phenolic solution	A	1 hr 180°F 3/4 hr 325°F
181	Proprietary resorcinol-formaldehyde	A	1 hr 165°F

* Table II
† Parts per hundred parts resin by weight

These ingredients are usually compounded in a solution for coating onto the substrates prior to drying and curing, but may also be available in film form. Some of these formulations have been used successfully for many years in such applications as brake lining bonding and aircraft honeycomb panel bonding. The resorcinol-formaldehyde adhesive (#181) is known for its extremely durable performance in marine plywood.[6] Its chemistry is similar to a phenolic (novolac) which requires a hardener for thermosetting. This type of adhesive performs best on porous or coreactive materials.

Polysulfide polymers are generally used as sealants with some adhesive properties, as in #203, and as flexibilizers for epoxy systems as in #176 and #202. As sealants, polysulfide rubbers have gained a reputation for excellent chemical, thermal, and weather resistance.

Table IV—Adhesive Systems for Stainless Steel Subtrates

Reference Number	Adhesive Description	Surface Preparation*	Cure Cycle
	Initial Phase		
191	Proprietary, paste, modified DGEBA epoxy based formulation plus 6 phr† diethylaminopropylamine	B	4-1/2 hr 200°F
192	Proprietary, paste, modified DGEBA epoxy based formulation plus 6 phr diethylaminopropylamine (same material as #178)	B	4-1/2 hr 200°F
193	Proprietary, two-part aluminum metal filled, nominally room temperature curing epoxy repair kit (same material as #177)	C	2 hr 165°F
194	Proprietary poly (vinyl formal)-modified phenolic tape (same material as #179) plus primer solution	B	1 hr 225°F plus 1 hr 325°F
195	Proprietary poly (vinyl butyral)-modified phenolic film plus primer solution	B	1 hr 225°F plus 1-1/2 hr 300°F
196	Liquid diluent modified DGEBA epoxy resin plus 100 phr liquid polyamide plus 40 phr of a proprietary mineral filler	C	1 hr 250°F
	Second Phase		
197	Proprietary, one-part, high viscosity, modified-epoxy adhesive	D	1 hr 350°F
198	Proprietary, one-part, thixotropic, modified-epoxy adhesive similar to #197	D	1 hr 350°F
199	Proprietary, high-temperature-resistant, modified-epoxy adhesive film with fabric carrier	D	1 hr 350°F
200	Proprietary, highly metal-filled, two-part (100 to 9 mix ratio), low viscosity adhesive	D	3 hr 180°F plus 3 hr 250°F
201	Liquid DGEBA epoxy resin plus 20 phr liquid aromatic primary amine blend same as #172	D	2 hr 250°F
202	Liquid DGEBA epoxy resin plus 15 phr liquid aromatic primary amine blend plus 40 phr liquid polysulfide polymer	D	2 hr 250°F
203	Proprietary black polysulfide paste compound plus 12 phr lead dioxide curing agent	D	2 hr 140°F
204	Proprietary, one-part, paste, high-temperature-resistant, aluminum filled, modified DGEBA epoxy	D	2 hr 350°F

* Table II

† Parts per hundred parts resin by weight

2.3 *Results and Discussion*

2.3.1 *Glass Fiber Substrates*

The test results obtained on the bonded glass fiber specimens were essentially independent of the adhesive, except for the sample bonded with the resorcinol-formaldehyde adhesive (#181). With all of the other adhesives, and at every aging and conditioning sequence, the adhesive joint did not fail during testing. The failures occurred between the first and second layers of glass mat in one of the substrates and over the joint area, then proceeding to break across the glass mat just beyond the end of the overlap. In actuality, then, the values obtained measure only the interlaminar shear strength plus the tensile strength of a single glass ply of the substrate. Figure 2 is a plot of the test results obtained at the various aging conditions for one of the adhesive systems. All of the systems followed this pattern with a maximum deviation from this plot of about 10 percent for any value except for sample #181. These deviations, although within the range expected for this type of failure, show another anticipated trend in that the more flexible (tough) adhesive formulations tend toward the higher end of the spectrum while the more brittle formulations fall at the lower end. This is an indication of the ability of flexible adhesives to distribute stresses on rigid or friable substrates more evenly than brittle adhesives. The anomalously high values shown for the four-year Roswell specimens were typical of each system and have not been explained.

The specimens of #181 resorcinol-formaldehyde adhesive were the

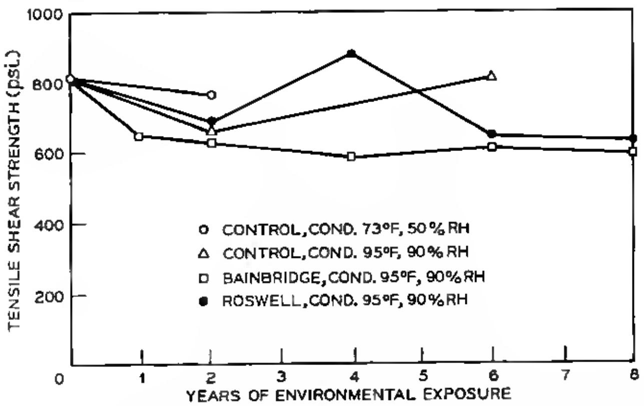

Fig. 2—Tensile shear strength of typical adhesive bonded glass fiber test specimens vs years of environmental exposure.

only ones in this group to exhibit failure apparently at the adhesive interface, and at values less than half the typical values shown in the plot. This type of adhesive is mainly used for waterproof wood bonding, but it has very high shrinkage on cure and is normally considered too brittle for most nonporous substrates (nylons and acrylics being notable exceptions).

Since laminate failure occurred in all other cases, the conclusion may be drawn from Fig. 2 that the adhesives were not severely attacked by the environment. It also indicates that sandblasting of the glass fiber laminate substrate is a viable surface preparation method. The glass fiber laminates themselves exhibit a mild deterioration in strength characteristics, but that apparently levels off with minimum additional changes. Further information on the effects of soil burial on structural laminates is presented in a companion article by T. H. Klein.[7] There was no significant difference between the specimens buried in the topsoil and those in the subsoil, nor between those at the two burial sites.

2.3.2 *Stainless Steel Substrates*

The initial group of bonded stainless steel specimens for this program proved to be seriously deficient in surface preparation. Figure 3 shows

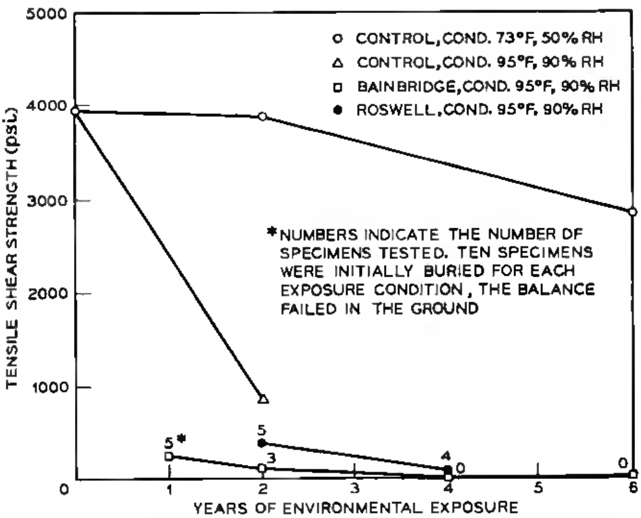

Fig. 3—Tensile shear strength of typical adhesive bonded stainless steel test specimens #191 to 196 vs years of environmental exposure.

the test results of Adhesive #191 and is typical of all tbe samples in this category. The initial lap shear values range from 3000 to 6000 psi and show losses of from 25 to 60 percent after six years of indoor storage and 30 days of laboratory conditioning (73°F, 50-percent RH) prior to testing. Additional specimens stored indoors for only two years but conditioned at 95°F and 90-percent RH for 30 days before testing exhibited losses in lap shear strength between 75 and 100 percent of the corresponding standard lab-conditioned specimens. Since all of the buried specimens were subject to the latter treatment prior to testing, poor results were obtained. Approximately 65 percent of tbe Bainbridge and 85 percent of the Roswell specimens had failed in the ground prior to testing. Of those samples that survived burial, the test results with only a few exceptions were under 1000 psi, and mostly under 500 psi. The significant decrease in lap shear strength for all of the specimens exposed to humidity versus similar but dry specimens is an indication that neither surface preparation (B or C) of the stainless steel substrates was optimum. Additionally, three of the adhesives in this group were also included in the glass fiber laminate series where no similar humidity-related degradation was noted.

Because of the poor performance of this group of specimens, and the concurrent development of the improved prebond surface preparations for stainless steel, the early (#191 to 196) portion of the burial program was terminated after six years, and a new group of stainless steel bonded specimens prepared. Newer adhesives were substituted in the

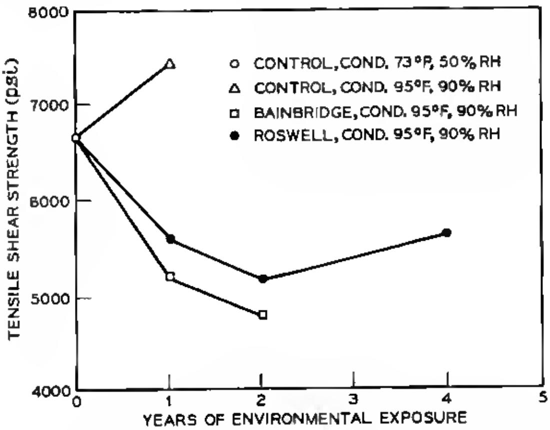

Fig. 4—Tensile shear strength of #197 adhesive bonded stainless steel test specimens vs years of environmental exposure.

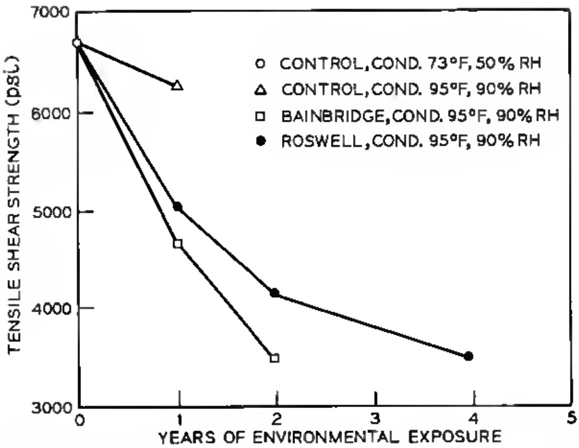

Fig. 5—Tensile shear strength of #198 adhesive bonded stainless steel test specimens vs years of environmental exposure.

second phase of the program to take advantage of advancing technology and, in the case of the polysulfide rubber, to provide specific application related information.

Figures 4 to 11 are plots of the available test data on the performance of the second group of stainless steel bonded joints (samples #197 to 204). At the time of this writing, only one- and two-year Bainbridge and one-, two-, and four-year Roswell data were available. Test results for subsoil and topsoil specimens were essentially identical and were combined for the data analysis. Figure 4 shows the joint strength decreasing some 25 percent for Bainbridge and about 20 percent for Roswell over one and two years, while the shelf control increased about 15 percent the first year. The major portion of the loss in strength of the buried specimens is in the first year, while Roswell shows a mild recovery of its four-year specimens.

Figure 5 shows losses at two years of 40 and 50 percent for Roswell and Bainbridge respectively, with only slight indications of change in slope. The four-year Roswell specimen does indicate a tapering off in the loss of joint strength. The one-year shelf control also shows a slight decrease in strength compared to the original values. Very surprising is the difference between #197 and #198 which are made by the same manufacturer and to the same formulation, except for the inclusion of a small amount of a filler to impart thixotropic properties to #198.

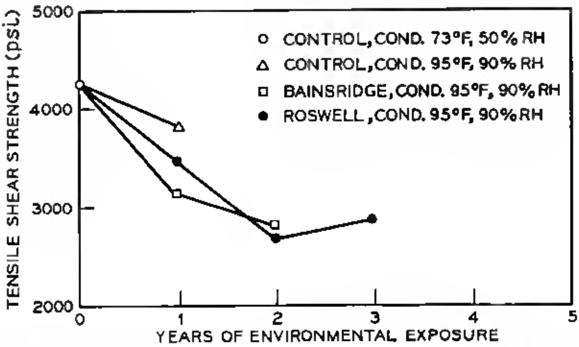

Fig. 6—Tensile shear strength of #199 adhesive bonded stainless steel test specimens vs years of environmental exposure.

Adhesive systems #199 and #200, shown in Figs. 6 and 7, exhibit general behavior patterns similar to #197 and #198 with about 25 to 35 percent decrease in joint strength after two years burial and some indication of leveling off.

Adhesive systems #201 and #202 (Figs. 8 and 9) show the effects of soil burial on two adhesive systems having equivalent bases, but incorporating a liquid polysulfide flexibilizer in #202. The initial and one-year laboratory controls of the flexibilized system are about double those of the unmodified adhesive. The unmodified adhesive exhibits a moderate decline in joint strength as a result of the soil burial, while the flexibilized adhesive loses all of its initial advantage within the first year, then parallels the unmodified system.

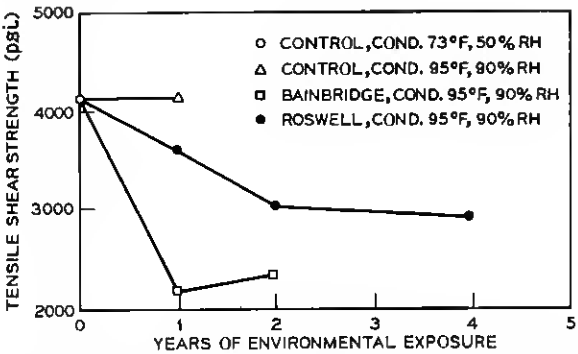

Fig. 7—Tensile shear strength of #200 adhesive bonded stainless steel test specimens vs years of environmental exposure.

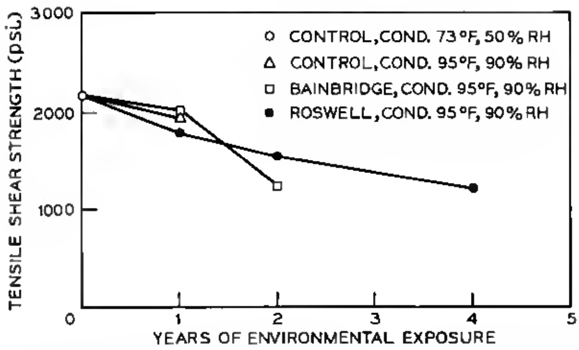

Fig. 8—Tensile shear strenght of #201 adhesive bonded stainless steel test specimens vs years of environmental exposure.

Figure 10 illustrates a pattern similar to most of the epoxy systems under test in that a gradual decrease in joint strength is found with soil burial.

The one non-epoxy system in the second group of adhesives with stainless steel substrates is shown in Fig. 11. This two-part polysulfide rubber, which is considerably lower in strength than the epoxy system,

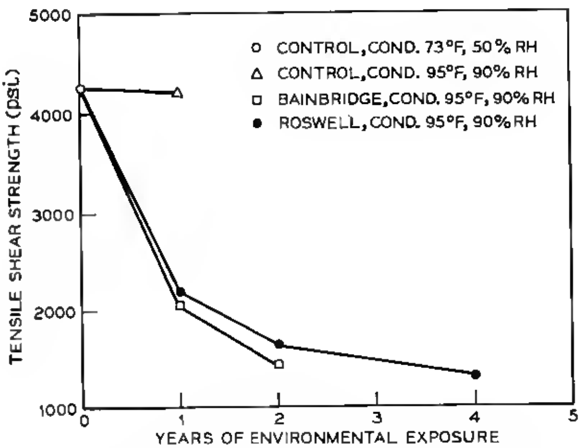

Fig. 9—Tensile shear strength of #202 adhesive bonded stainless steel test specimens vs years of environmental exposure.

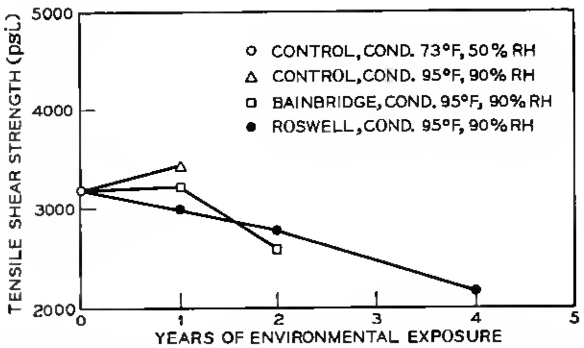

Fig. 10—Tensile shear strength of #204 adhesive bonded stainless steel test specimens vs years of environmental exposure.

actually shows a slight tendency toward increased joint strengths as a result of burial.

The changes in joint strength of the variety of buried epoxy adhesive bonded stainless steel specimens do not provide complete insight into the mechanism(s) of deterioration involved; however, some useful observations can be made. In most cases, the buried samples show significantly lower values than the one-year shelf control, indicating a definite degradation caused by the earth environment. Humidity or moisture effects during pretest conditioning can be ignored since all of the specimens and controls were exposed to the same 30-day, 95°F, 90-percent RH. Also apparent is a tendency for Bainbridge to be a harsher environment than Roswell. Because of the absence of fugitive adhesive components, the rate of joint strength loss in this group of samples does not appear to indicate a biological type degradation of the epoxy adhesives, since one might expect a more rapid and complete

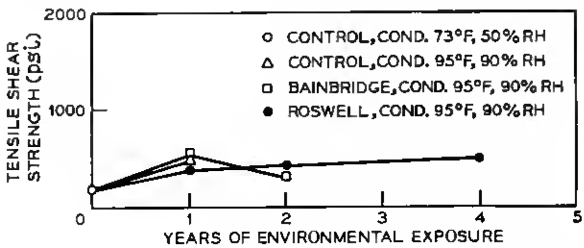

Fig. 11—Tensile shear strength of #203 adhesive bonded stainless steel test specimens vs years of environmental exposure.

failure of the specimens or, at least, no indications of leveling off. The significant difference in the behavior of #197 and #198 is indicative of a chemical attack on the filler which is probably a mineral type material. Conversely, #200 and #204 both contain metal (aluminum) fillers and neither of these exhibits the large decrease in strength experienced by #198. Of particular interest is the behavior of #201 and #202, which fits a pattern most easily explained by the leaching of unreacted polysulfide polymer that was acting only as a plasticizer. It may indicate that the typical epoxy chain extension and subsequent crosslinking caused by polysulfide/amine combinations may not occur with primary aromatic amines when cured at 250°F. This would leave the polysulfide as an unreacted and fugitive plasticizer. Additional shelf-aging data may confirm this when they become available.

A mechanism which may be controlling the degradation of the epoxy stainless steel systems is either a slow soil-chemical attack on the epoxy base resin or possibly a chemical attack at the metal/adhesive interface.

Little can be said about the polysulfide rubber system from only tensile shear data; however, one would expect that a crosslinking reaction was taking place while it was buried and that other changes such as lower elongation and increased hardness would also result.

2.4 *Engineering Implications of Data*

It is apparent, from the data presented, that adhesives can provide useful service under soil burial conditions. Most epoxy and modified-phenolic systems appear to offer adhesive qualities superior to the interlaminar shear strength of glass fiber laminates even after eight years of unstressed burial. The experiments indicate that abrasion is a satisfactory surface preparation for these laminates, and that it is possible to design joints which would be suitable for buried telephone plant applications.

The bonding of stainless steel for direct soil burial also appears to be a viable technique provided adequate care is taken in the surface preparation of the substrates. Deterioration of the ultimate load-bearing capability is experienced, with indications of continued declines after four years; however, the strength levels of some systems are well above typical requirements for bonded structures and they would be expected to perform satisfactorily with proper joint design. It must be emphasized that the data presented are the ultimate strengths after environmental conditioning without external loads. It has been shown[8,9] that the failure of some adhesive bonded test joints under moderate

static stress was hastened by the presence of high humidity. Additionally, most practical joint designs incur a combination of static and dynamic loading which experience has shown to be a more severe condition than static loading alone. Appropriate joint designs would take account of these factors.

III. PRESSURE-SENSITIVE TAPES

3.1 *Description of Tapes Tested*

3.1.1 *Types of Material*

Four types of tape (three pressure-sensitive adhesive and one composite rubber) were included in the soil burial program. All of the tapes were commercial products purchased under a Bell System specification and in general use at that time. The pressure-sensitive adhesive tapes included samples with vinyl, aluminum, and glass fabric backing, while the rubber tape was composed of a layer of vulcanized rubber coated with a layer of tacky, unvulcanized rubber. A more complete description of the four tapes is provided in Table V.

3.1.2 *Expected Service Life*

A variety of factors (approximately equivalent to the number of different applications) govern the expected service life of a pressure-sensitive tape.

The specification grade of vinyl tape included in this program is intended for use in splicing plastic-sheathed cables. The author would expect a service life of perhaps twenty years in buried environment; however, other applications have been noted where vinyl tapes become unsatisfactory in much shorter periods.

The glass tape is intended to serve as a mechanical reinforcement

Table V—Pressure-Sensitive Adhesive Tape Characteristics

Characteristic	Vinyl Tape	Glass Tape	Aluminum Tape	Rubber Tape
Overall thickness, inch	0.009–0.011	0.006–0.008	0.004–0.005	0.045–0.050
Backing	Plasticized vinyl	Glass cloth	0.003-inch aluminum foil	0.015-inch vulcanized rubber
Adhesive type	Rubber-resin	Rubber-resin	Rubber-resin	Unvulcanized rubber

in making gastight cable sheath closures. Very long service life (20–40 years) would be expected because of the stability of the glass, provided the installation did not permit unraveling due to adhesive failure.

The aluminum tape is intended to provide a mechanical reinforcement and a moisture barrier for cable sheath closures and should have a service life similar to the glass tape above, provided the thin aluminum backing is either adequately protected, or is not in direct contact with either a strongly acid or alkaline soil.

The rubber tape is used for splicing station wire, distributing wire, and cables. Its service life would be expected to run 10–20 years depending on atmosphere conditions, particularly ozone concentration.

3.2 *Materials*

3.2.1 *Tapes*

Pressure-sensitive adhesive tape can be described generally as a flexible backing material which has been coated with a tacky adhesive. Figure 12 shows a sectional view of a tape including features that may be optional for some tapes.

The four types of tape used in this program are all proprietary with respect to their specific composition and formulations. The tapes were purchased against a Bell System specification which controls certain use and quality requirements, thus allowing the manufacturer con-

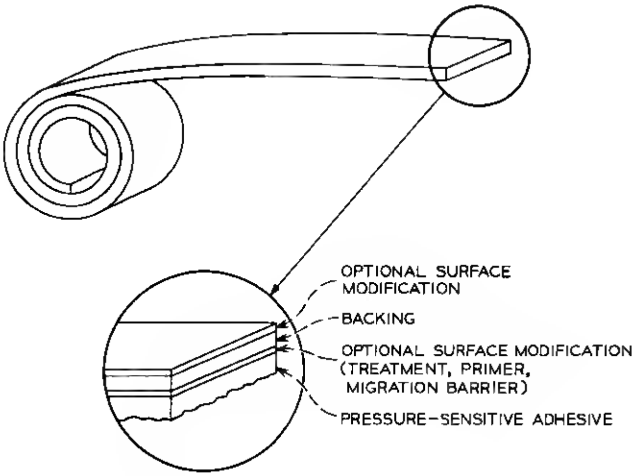

Fig. 12—Section through pressure-sensitive tape.

siderable formulating flexibility. Samples used in the Bainbridge burial were from different manufacturing runs from those used in the Roswell experiments, while the vinyl tape and the glass tape samples were obtained from different manufacturers.

3.2.2 *Backing*

The backing material of a tape is the major contributor to the physical properties of a tape and, because it is that part of a tape usually exposed to an environment, is most likely to experience considerable changes.

The vinyl tape uses a fairly soft or highly plasticized vinyl sheet for its backing. The vinyl formulation would typically consist of poly (vinyl chloride) resin, one or more plasticizers (mostly monomeric), stabilizers, coloring agents, fillers, and processing aids. Two mechanisms of deterioration exist: one is the loss of plasticizer through volatilization, extraction, or migration, and the other is dehydrochlorination due to the natural thermal instability of the vinyl resin. The stabilizers minimize deterioration by reacting with the HCl formed until they are all used up, at which point the degradation becomes very rapid, since it is catalyzed by the presence of free HCl.

The glass cloth used in the glass tape would normally be considered quite stable to most environments; however, the sizing or surface lubricant which reduces abrasion damage may be subject to chemical or biological attack. Damage to the aluminum foil backing would be expected to be exclusively chemical and reflect itself as a decrease in strength. The rubber backing would be expected to undergo change, but the type of the change would depend on the specific interaction taking place, e.g., oxidation, crosslinking, chain scission, etc.

3.2.3 *Adhesives*

The adhesives used on pressure-sensitive tapes are generally based on a rubber (either natural or synthetic) that has been compounded with a variety of modifiers such as stabilizers, tackifiers, antioxidants, curing agents, colorants, reinforcing agents, fillers, extenders, etc. In thin layers, the adhesives are usually applied as emulsions or from solvent solution; in greater thicknesses they may be calendered onto the backing. Degradation of the adhesive layer by a soil environment would be expected to proceed slowly, unless the backing were attacked rapidly to provide access to the adhesive or if some component were readily leached by surface water.

3.3 *Test Methods*

3.3.1 *General*

Physical property tests for pressure-sensitive tapes are generally oriented toward either the adhesive or the backing even though there can be a significant interplay. In this program, tensile properties of the backing and peel adhesion of the adhesives were used to determine the effects of soil burial. All of the tapes were tested for tensile strength while the two extensible tapes were also tested for elongation and "modulus" (load) at 50-percent elongation for the vinyl and at 200-percent elongation for the rubber. The significance of the "modulus" number is an indication of the force necessary to provide a common degree of application stretch; however, when measured after soil burial the data provide an indication of embrittlement.

"Adhesion" was measured as a T-peel test of one adhesive tape to the back of another piece of the same tape. This procedure had the advantage of minimizing data scatter caused by difficulties in obtaining uniformly clean surfaces for peel test.

3.3.2 *Sample Preparation*

Individual test specimens were prepared for both the peel and tensile tests prior to soil burial. The tensile specimen was made by laminating two strips of tape together (adhesive to adhesive) and then die cutting the required dumbbell specimen.* Tensile strength, elongation, and "modulus" were all determined from these specimens, if applicable.

The specimens for peel testing were prepared by applying a strip of tape to a hard surface, applying a second strip on top of the first, then trimming to a 3/4 inch width. The exposed adhesive face was covered with 0.001-inch polyethylene film to protect it from the soil. One end of the specimen was separated for 2 inches to allow gripping by the testing machine.

3.3.3 *Sample Testing*

All tape testing was conducted on an Instron Testing Machine under the conditions shown in Table VI. The values for tensile properties are expressed in terms of pounds per inch of width, and the adhesion as ounces per inch of width.

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* ASTM D412 Die C.

Table VI—Tape Testing Parameters

Material Type	Tensile Tests: Crosshead Speed in/min	Tensile Tests: Full Scale lbs load	Adhesion Tests: Crosshead Speed in/min	Adhesion Tests: Full Scale lbs load
Vinyl	12	20	12	2
Aluminum	0.02	20	12	2
Glass	12	50	12	2
Rubber	20	20	12	5

3.4 *Results and Discussion*

3.4.1 *Vinyl Tape*

Figure 13 shows graphically the changes in the four test values obtained on the vinyl tape as a function of aging time. The six lines in each graph represent indoor storage and burial in both topsoil and subsoil for the samples used in the two exposure locations.

Neither of the two samples of vinyl tape shows very large changes in its physical properties; however, subtle differences can be detected which follow distinct patterns. In the tensile strength area, we see that the Bainbridge specimens experience very little decrease while the control shows about a 15-percent increase. The Roswell specimens show a slight decrease with very little difference between top soil and subsoil specimens while the control shows about a 10-percent decrease. Elongations decreased significantly for the Bainbridge samples, including the shelf-aged control, while the two buried Roswell samples decreased less but mainly after two years of burial. The unusual result in this group was the control for the Roswell samples which showed an increase in elongation of almost 25 percent after two years.

The Roswell control actually fits a pattern of increase in plasticizer content since the tensile strength and "modulus" decreased and the elongation increased. This, however, is not the typical behavior of a plasticized vinyl, which tends to lose plasticizer on aging and follows the pattern of all the other specimens, e.g., tensile and modulus increase with elongation decrease.

The modulus changes show very close parallels for all three aging conditions of the Bainbridge specimen and the two buried Roswell specimens. It appears that the Roswell control specimen was inadvertently allowed to absorb plasticizer, either from another plasticized vinyl or from an accidental spill.

The two manufacturers' samples show adhesion values which are unaffected by the burial environment, since extremely close alignment of values occurred between topsoil, subsoil, and control for each sample over the period of the test. The absolute values for the Roswell sample showed increased adhesion values of almost 25 percent while the other sample decreased by a similar amount. The increase in adhesion values might be a result of the increase in backing modulus or stiffness plus, perhaps, a very slight crosslinking in the adhesive and a small contribution from a phenomenon known as "building tack." Building tack is a time-dependent function of the adhesive's ability to wet out a surface completely. Most pressure-sensitive adhesives will achieve 99 percent of their building tack in from 1 to 7 days. The fact that

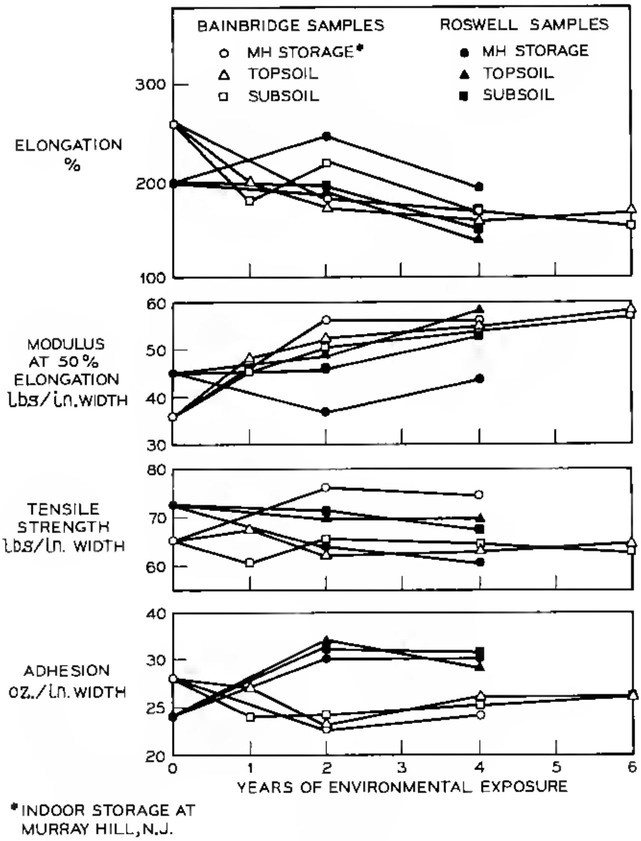

Fig. 13—Vinyl tape test results vs years of environmental exposure.

the sample from Bainbridge showed decreases in adhesion, despite significant increases in stiffness of the backing, shows that the adhesive is being degraded. This may take the form of oxidative degradation, beyond the stage of mild crosslinking, or plasticizer migration where the adhesive absorbs plasticizer from the backing and becomes soft and stringy with a much lower cohesive strength.

3.4.2 *Glass Tape*

The test results from the glass tape evaluation are shown in Fig. 14. In general, it can be seen that not only soil burial but also shelf aging had a marked effect on the tensile strength and adhesion values of the glass tape. Also shown is the difference in aging pattern at the two

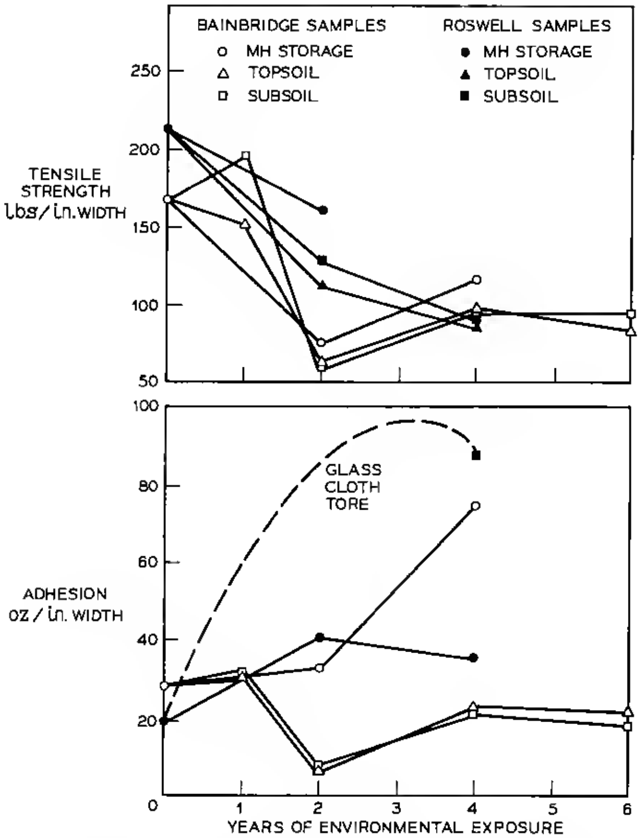

Fig. 14—Glass tape test results vs years of environmental exposure.

burial sites, but since different manufacturers' products were used at each location, it may be difficult to draw useful conclusions.

The specimens buried at Roswell showed a significant and steady decrease in tensile strength for both topsoil and subsoil conditions. Two-year shelf aging also produced a significant decrease in tensile strength, but less than the buried specimens. The specimens buried at Bainbridge were somewhat more erratic in their tensile strength values, e.g., the one-year subsoil specimens were actually higher than the original test value, while the two-year specimens were very low and four- and six-year specimens were higher in value than the two-year specimens.

Adhesion values are also erratic, e.g., the Roswell shelf-aged control doubled in two years while the glass tore in the buried specimens before the adhesive failed. After four years, a value of 88 oz/in of width was obtained on the subsoil buried specimens, or over four times the unaged value. The topsoil specimens tore before adhesive failure, presumably at values above the 88 oz/in which was sustained by the subsoil specimens. The shelf-aged Roswell control exhibited a slight decrease after six years versus four years. The Bainbridge adhesion specimens behaved the opposite of the Roswell specimens. The shelf-aged control underwent very little change at two years, then rose rapidly to more than double the initial value at four years. Topsoil and subsoil buried specimens virtually overlapped each other in test values with the two-year specimens falling significantly out of line with an otherwise very gradual decrease.

The general performance of the glass tape is indicative of several important changes taking place. The glass backing itself is losing strength in both manufacturers' products. Presumably this is due to the sizing's loss of effectiveness in preventing mechanical (abrasion) damage to the glass fibers. The adhesive, on the other hand, shows significant differences for the two manufacturers. The Roswell samples show rapid crosslinking at ambient temperature conditions (limited shelf life) followed by a degradation of mechanical properties probably due to oxidation and embrittlement. The Bainbridge samples show a slower initial room temperature thermosetting rate followed by a very rapid one. The thermosetting rate was inhibited for the buried specimens, but sufficient data are not available to determine if the lower soil temperature or the soil chemistry was the inhibiting factor.

3.4.3 *Aluminum Tape*

Figure 15 shows the test results for the aluminum tape. Samples buried at Roswell showed very little difference in tensile strength from

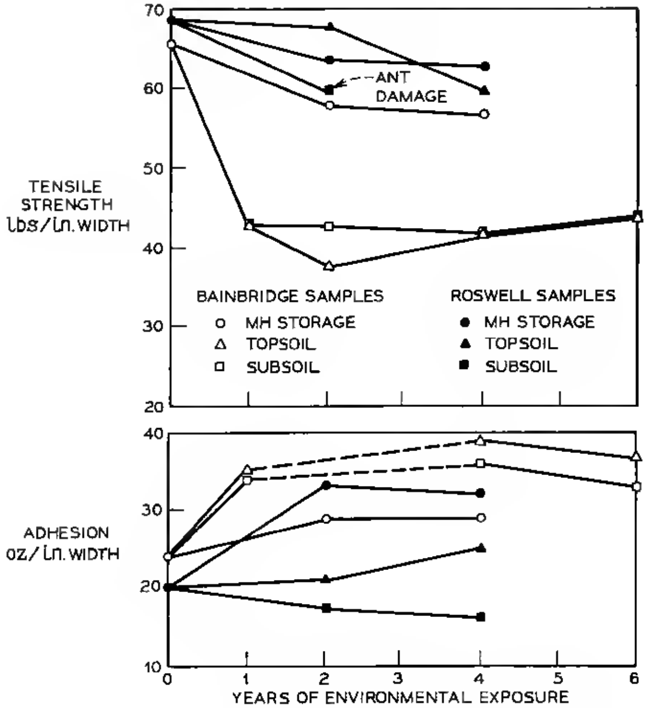

Fig. 15—Aluminum tape test results vs years of environmental exposure.

the control (shelf-aged) specimen up to four years, except that the four-year subsoil specimens showed ant damage and were not tested. The first-year specimens buried at Bainbridge were approximately 30 percent below the initial values and continued considerably below the control after subsequent periods. It is apparent that the acid condition of the Bainbridge soil had at least an initial corrosive effect on the aluminum backing, whereas the mildly alkaline Roswell did not.

Adhesion values for the Roswell samples remained relatively constant, the subsoil specimens showing a slight decrease, and the topsoil specimen a slight increase over the control. The two- and four-year shelf-aged specimens both exhibited a large increase over the initial value. The Bainbridge results, except at two years, are considerably higher than the Roswell specimens and their own shelf-aged controls. The Bainbridge shelf-aged control did not exhibit the same magnitude of increase in adhesion as shown by the Roswell control. This can be attributed to differences in the adhesive coating and its concentration of cross-

linking agents or to the possibility of an inordinate delay in obtaining the initial test results, which would have allowed the building tack factor time to increase the initial value.

3.4.4 *Rubber Tape*

Figure 16 illustrates the test results obtained on shelf-aged and buried specimens of rubber tape. It should be remembered that the rubber tape is much thicker than a regular tape (0.045 inch with 2/3 unvulcanized white rubber and 1/3 of vulcanized dark rubber). All original and shelf-aged specimens exhibited very little change except for adhesion.

Significant changes occurred in the buried specimens mainly over the first period of test. Values for the topsoil and subsoil specimens

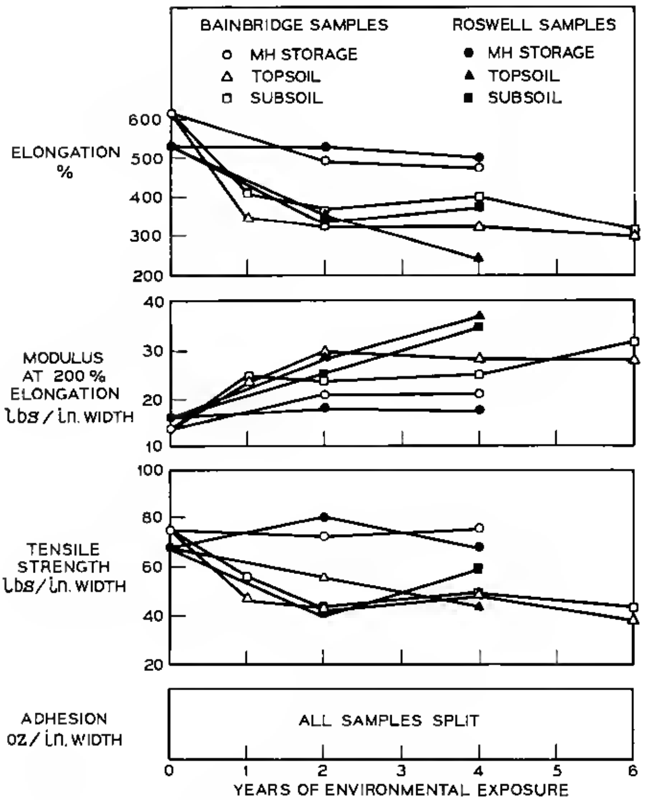

Fig. 16—Rubber tape test results vs years of environmental exposure.

were very close indicating little dependence on the depth of burial. Losses of up to 45 percent in elongation and 40 percent in tensile strength and gains of about 100 percent in modulus could be attributed to the soil burial. Adhesion values were not plotted because of the nature of the tape and the fact that after the initial tests all readings were no longer adhesion but tear in the white rubber at values in the range of 200 oz/in of width.

The deterioration in physical properties of the rubber tape is most likely due to biochemical attack causing oxidation and embrittlement of both the vulcanized and unvulcanized portions of the tape.

3.5 *Engineering Implications Of Data*

The test methods for the soil burial program on tapes were chosen so as to learn as much about the properties of the tape as possible. It is now appropriate to discuss these changes in properties in terms of the performance of a tape in a typical use context.

A vinyl tape installed properly over a cable or conduit for soil burial would be expected to cause no problem based on the findings of this study. The changes in elongation capability and the increased stiffness of the backing would not have a functional bearing on the cable, nor would it cause the tape to cease performance of its function. It would indicate that a tape exposed to the environment would not be suitable for reuse were it to be removed.

The glass tape shows characteristics which would be of concern for other than temporary applications. In particular, the rapid deterioration of tensile strength and the erratic adhesion performance are undesirable, especially since the glass tape would be used on high-stress applications. This could mean that even the slightest movement or differential expansion of an underground cable could cause a loss in adhesion or an actual tensile break.

The aluminum tape ages well under burial conditions but exhibited some attack in the more acid soil of Bainbridge. It is assumed that adequate protection of the thin aluminum backing (by overcoating with a barrier material) would retard the corrosion in both strong acid and alkaline soils. The main purpose of the tape as a moisture barrier would then remain in effect.

The rubber tape, although degraded by soil burial, should still provide reasonable service. The amount of deterioration is insufficient to cause a mechanical failure since adequate amounts of elongation and tensile strength remain after long exposure to soil environments.

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REFERENCES

1. Connolly, R. A., "Soil Burial of Materials and Structures," B.S.T.J., this issue, pp. 1–21.
2. *ASTM—Standards Book 16*, Philadelphia: American Society For Testing and Materials, 1970.
3. Skeist, I., *Epoxy Resins*, New York: Reinhold Publishing Corp., 1964.
4. Lee, H., and Neville, K., *Epoxy Resins*, New York: McGraw-Hill, 1957.
5. Lee, H., and Neville, K., *Handbook of Epoxy Resins*, New York: McGraw-Hill, 1967.
6. Bruno, E. J., *Adhesives in Modern Manufacturing*, Dearborn, Michigan: Society of Manufacturing Engineers, 1970, p. 8.
7. Klein, T. H., "Effect of Soil Burial Exposure on the Properties of Structural Grade Reinforced Plastic Laminates," B.S.T.J., this issue, pp. 51–62.
8. Rider, D. K., "Adhesives Engineering," Trans. N. Y. Acad. Sci., Series II, *29*, No. 6 (1967), pp. 711–721.
9. Sharpe, L. H., "Some Aspects of the Permanence of Adhesive Joints," Appl. Polym. Symposia, *3*, (1966), pp. 353–359.